Proceedings of 9th Asian-Pacific Regional IAU Meeting 2005, 1–2 (2005) Printed 4 February 2008 (APRIM LaTeX style file v1.0)



# The Evolving Structure of Galactic Disks

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**ABSTRACT**
Observations suggest that the structural parameters of disk galaxies have not changed greatly since redshift 1. We examine whether these observations are consistent with a cosmology in which structures form hierarchically. We use SPH/N-body galaxy-scale simulations to simulate the formation and evolution of Milky-Way-like disk galaxies by fragmentation, followed by hierarchical merging. The simulated galaxies have a thick disk, that forms in a period of chaotic merging at high redshift, during which a large amount of $\alpha$-elements are produced, and a thin disk, that forms later and has a higher metallicity. Our simulated disks settle down quickly and do not evolve much since redshift $z \sim 1$, mostly because no major mergers take place between $z = 1$ and $z = 0$. During this period, the disk radius increases (inside-out growth) while its thickness remains constant. These results are consistent with observations of disk galaxies at low and high redshift.

**Key words:** cosmology — galaxies: formation — galaxies: evolution

## 1 THE SIMULATIONS

We used the chemodynamical galaxy formation code GCD+ (Kawata & Gibson 2003), to simulate the formation of 4 disk galaxies of masses comparable to the mass of the Milky Way. The code includes self-gravity, hydrodynamics, radiative cooling, star formation, supernova feedback, and metal enrichment. The initial conditions consist of a uniform, slowly-rotating sphere of gas of mass $5 \times 10^{11} M_{\odot}$ onto which we superpose small density fluctuations. The systems initially fragment into several clumps that later collide and merge to form disk galaxies with 3 distinct structures: a thin disk, a thick disk, and a halo.

## 2 DISK FORMATION AND GROWTH

Figure 1 shows the age of stars vs. their height above the galactic plane and their distances from the galactic center, for one simulated galaxy. This reveals the existence of two distinct disks. The thin disk is about 2 kpc thick, and is composed of old stars (> 9 Gyrs). Both disks extend to a radius of 10 kpc (Brook et al. 2005a).

Figure 2 shows the scale height $h_z$ and scale length $h_l$ of our 4 simulated galaxies, at 3 different epochs. The time sequence (stars → squares → triangle) shows that $h_l$ tends to increase with time while $h_z$ remains constant, indicating that disks grow "inside-out" (Brook et al. 2005b). The time sequence (circles → crosses), based on observations at $z = 1$ and $z = 0$ (Schwarzkopf & Dettmar 2000; Reshetnikov et al. 2003) is consistent with that result.

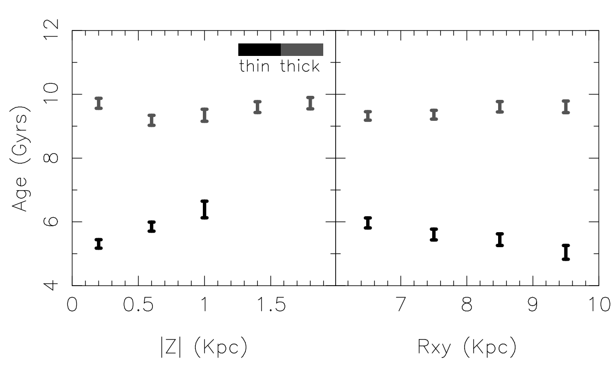


**Figure 1.** Age vs. height and galactic radius, for the thin disk (lower symbols) and the thick disk (upper symbols).

## 3 ABUNDANCE PATTERS

Figure 3 shows the abundances of $\alpha$-elements (O, Mg, and Si) vs. metallicity. The stars in the thick disk and halo form early. They are rich in $\alpha$-elements but poor in iron compared to the thin disk. The high abundance of $\alpha$-elements results from the high occurrence of Type II supernovae at early time, during the epoch of chaotic merging.

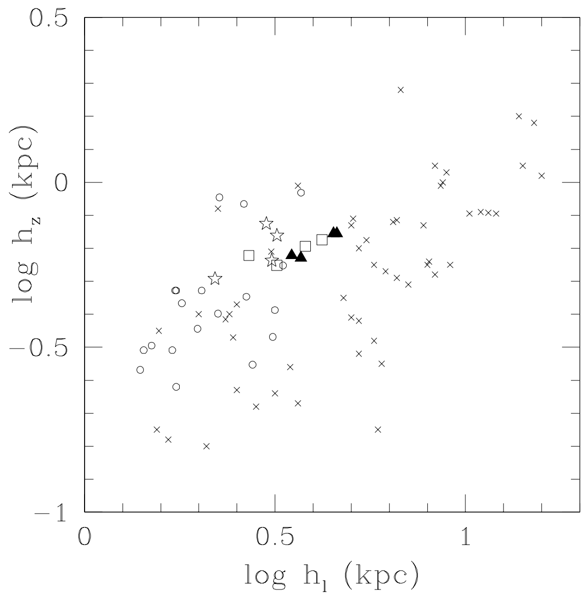


**Figure 2.** Scale-height $h_z$ vs. scale length $h_l$ for our 4 simulated galaxies, shown at redshifts $z = 1$ (stars), $z = 0.5$ (squares), and $z = 0$ (triangles). Also shown are observations of local disk galaxies (crosses) and edge-on galaxies at $z \sim 1$ (circles)

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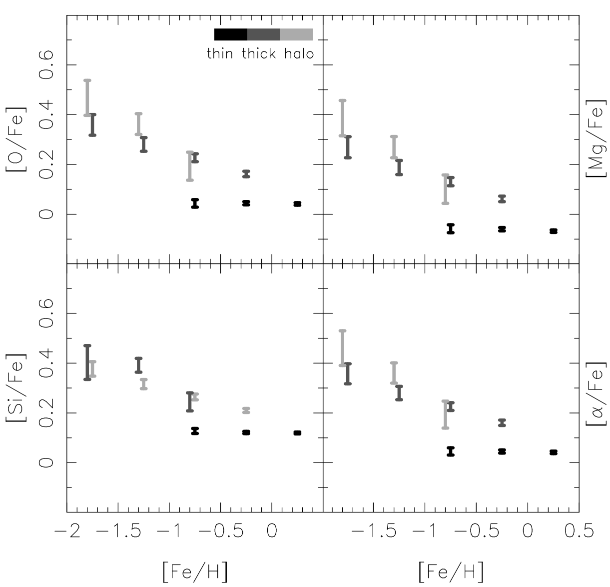


**Figure 3.** Abundance of $\alpha$-elements vs. metallicity, for stars in the thin disk (lower symbols), thick disk (middle symbols), and halo (upper symbols). The last panel shows the combined abundance of oxygen, magnesium, and silicon.

Figure 4 shows the gradients of metallicity. The metallicity of the thick disk tends to decrease with both height and distance from the center. For the thin disk, the metallicity decreases with height but does not vary with distance. There is a clear separation between the two components, the thick disk being significantly metal-poor compared to the thin disk (even though it is richer in $\alpha$-elements). Figure 5 shows a histogram of the number of stars vs. metallicity.

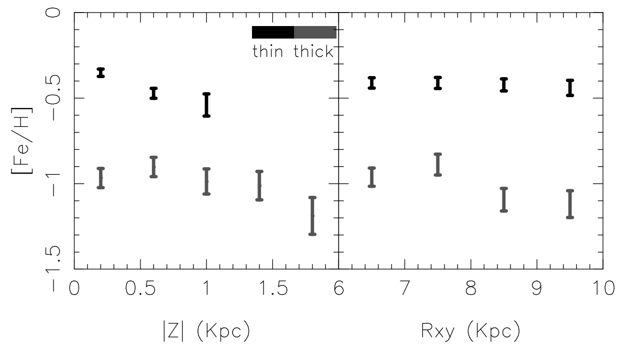


**Figure 4.** Metallicity vs. height and galactic radius, for the thin disk (upper symbols) and thick disk (lower symbols).

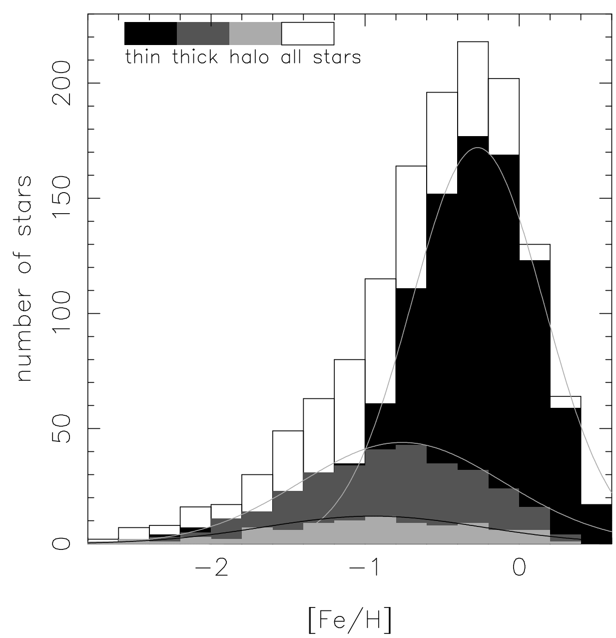


**Figure 5.** Number of stars vs.metallicity, for the thin disk (black), thick disk (dark gray), halo (light gray), and total (white). Each "star" is actually a computational object that represents $\sim 26,000$ stars.

The majority of stars are in the thin disk, and these stars have a higher metallicity than the thick disk or halo stars.

This work was supported by the Natural Science and Engineering Research Council of Canada. We are very thankful to Vincent Veilleux for producing several of the figures.

## REFERENCES

Brook C. B., Gibson B. K., Martel H., & Kawata D. 2005, ApJ 630, 298.

Brook C. B., Kawata D., Martel H., Gibson B., & Bailin J. 2005, ApJ, submitted

Kawata D. & Gibson B. 2003, MNRAS 340, 908

Reshetnikov V. P., Dettmar R.-J. & Combes F. et al. 2003, A&A 399, 879

Schwarzkopf U. & Dettmar R.-J. 2000, A&AS 144, 85